

**Manuscript version: Author's Accepted Manuscript**

The version presented in WRAP is the author's accepted manuscript and may differ from the published version or Version of Record.

**Persistent WRAP URL:**

<http://wrap.warwick.ac.uk/159645>

**How to cite:**

Please refer to published version for the most recent bibliographic citation information. If a published version is known of, the repository item page linked to above, will contain details on accessing it.

**Copyright and reuse:**

The Warwick Research Archive Portal (WRAP) makes this work by researchers of the University of Warwick available open access under the following conditions.

Copyright © and all moral rights to the version of the paper presented here belong to the individual author(s) and/or other copyright owners. To the extent reasonable and practicable the material made available in WRAP has been checked for eligibility before being made available.

Copies of full items can be used for personal research or study, educational, or not-for-profit purposes without prior permission or charge. Provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.

**Publisher's statement:**

Please refer to the repository item page, publisher's statement section, for further information.

For more information, please contact the WRAP Team at: [wrap@warwick.ac.uk](mailto:wrap@warwick.ac.uk).

# Simultaneous Monitoring of CD and OSNR Based on Delay-Tap Sampling and Image Processing

Jinsheng Xu<sup>1</sup>, Jian Zhao<sup>1,\*</sup>, Tianhua Xu<sup>1,2,\*\*</sup>, Kenneth K. Y. Wong<sup>3</sup>

<sup>1</sup> Key Laboratory of Opto-Electronic Information Technology, Ministry of Education, School of Precision Instrument and Opto-Electronics Engineering, Tianjin University, Tianjin 300072, China

<sup>2</sup> School of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom

<sup>3</sup> Department of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong, China

\*enzhaojian@tju.edu.cn

\*\*tianhua.xu@ieee.org

**Abstract**—We demonstrated a simultaneous CD and OSNR monitoring method for NRZ-OOK signals by employing the delay-tap sampling and image processing techniques. The monitoring ranges of OSNR and CD are 14-30 dB and 0-1275 ps/nm, respectively.

**Keywords:** optical performance monitoring; delay-tap sampling; image processing;

## I. INTRODUCTION

Optical performance monitoring (OPM) is an important function in high speed and dynamic reconfigurable optical network systems. Many OPM techniques have been proposed to monitor a single optical transmission system parameter such as optical signal-to-noise ratio (OSNR), chromatic dispersion (CD) and polarization mode dispersion (PMD) [1-3]. Since the performance of an optical communication system is often decided by a combination of system parameters, it is essential that a technique can be developed to monitor more than one parameter simultaneously. Delay-tap sampling technology has been widely used in the OPM tasks that enables multi-parameter signal monitoring [4-6]. It employs a tap delay line to sample the time domain signal twice during one sampling process. Although the signal waveform change can be reflected by the scatter plots using the sampled data, the monitoring results are limited to qualitative analysis. Schemes have been proposed to quantify the monitoring results using pattern recognition and artificial neural network but large amount of data and calculation for initial training are needed [7]. In this paper, we employ image processing technique in dealing with the delay-tap sampling results. This method is based on relative measurement so it is not influenced by the power of the received signal and can avoid vast calculation for training. Not only quantitatively results can be obtained but also simultaneously CD and OSNR monitoring can be realized.

## II. PRINCIPLE

### A. Definition of OSNR

The conventional definition of OSNR with a 12.5 GHz noise bandwidth is given by [8]

$$OSNR(dB) = 10 \log_{10} \left( \frac{P_s}{P_n} \cdot \frac{B_o}{12.5 \text{ GHz}} \right) \quad (1)$$

where  $B_0$  is the noise equivalent bandwidth of the optical channel which is determined by the optical bandpass filter.  $P_s$  and  $P_n$  are the total power of the optical signal and the ASE noise within the optical bandwidth  $B_0$ . In-band OSNR is often difficult to be measured directly but can be decided indirectly from electrical signal-to-noise ratio (SNR). The electrical SNR is mainly dominated by the signal-spontaneous beat noise generated at the photodetector. If we include only this dominant contribution, the electrical SNR is related to OSNR by [9]

$$SNR_{el} = \frac{B_o}{2\Delta f} OSNR \quad (2)$$

$B_0$  is the bandwidth of the optical filter and  $\Delta f$  is the electrical noise bandwidth of the receiver. If we can measure the electrical SNR, then the OSNR can be obtained.

### B. Delay-tap sampling and image segmentation

Delay-tap sampling method was proposed recently. This method employs a delay-tap line to sample the time domain signal twice in a single sampling process. A pair of data can be obtained from the same or the adjacent data symbols. Using  $x$  and  $y$  to represent the first sampling point and the second sampling point, a two-dimensional scatter plots can be constructed using the data pair  $(x, y)$  for X axis and Y axis. Because the data pairs are from the same or adjacent pulses, the scatter plots can reflect the pulse shape change caused by the system impairments through its unique characteristics.

Two-dimension scatter plots can reflect the pulse shape change and noise information. Fig. 1 (a) shows the scatter plots of NRZ-OOK signal with 1 bit delay when OSNR is 20 dB. As shown in Fig. 1 (a), the width of all edges increases when noise is added to the signal. The y value of the scatter points in top edge can be obtained mainly from the flat part

of successive marks. Since the y value of top and bottom edges and x value of left and right edges are obtained from successive 0 or 1, so the amplitude distribution is only related to noise and is independent of CD. This enables us to apply image processing technique for separating the effect of

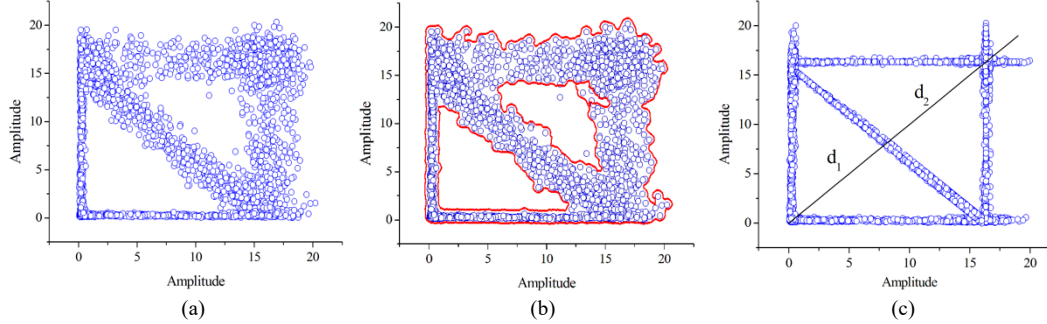


Fig. 1 The process of the image processing: (a) delay-tap plots with OSNR of 20dB; (b) the plots after image segmentation; (c) the plots after contraction.

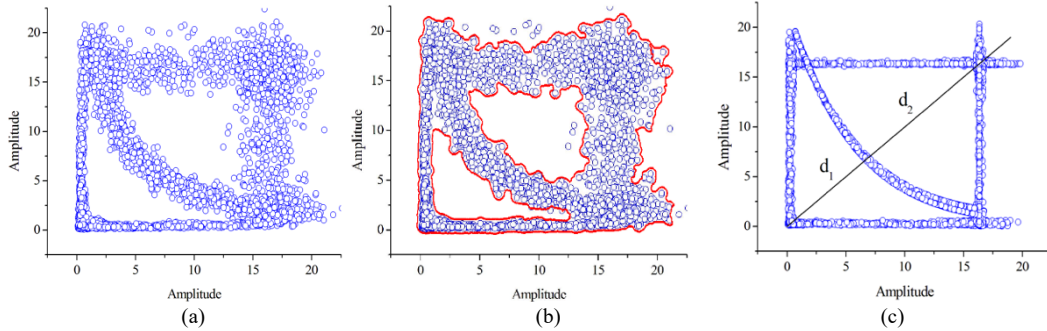


Fig.2 (a) The scatter plots with CD of 680 ps/nm and OSNR of 20 dB; (b) segmentation results; (c) the plots after image contraction.

noise and CD. Here to the best of our knowledge, image segmentation technique is employed for the first time in OPM monitoring area. Image segmentation is useful in many applications for identifying regions of interest in a scene. Here, the JSEG algorithm [10, 11] is used to analyze the delay-tap scatter plots. By applying the segmentation technique to the image, we can obtain the contour of the interested region of the plots as shown in Fig. 1 (b). Then we can calculate the average value of the edges and shrink the edges to the average value. Finally, the noise free scatter plots are recovered as shown in Fig. 1 (c). Top and right edge is broader than bottom and left edge since the signal-spontaneous beat noise is the dominant term. The square of mean value and variation of the top or right edge are calculated to represent the signal and noise power level. Then the OSNR can be calculated by equation (1) and (2).

CD causes the pulses to broaden so the rising edge and falling edge become less steep. Fig. 2 (a) shows the scatter plots with 680 ps/nm CD and OSNR of 20 dB. The diagonal bends to origin since the CD mainly affects the rising edge and falling edge. The flat part of successive 0 or 1 bits is nearly maintained with the increase of CD. The proposed method is used to remove the noise first and then the clean scatter plot with bending diagonal is obtained as shown in Fig. 2 (c). The linear function  $y=x$  is divided by the diagonal as shown in Fig.1 (c) and Fig. 2 (c).  $d_1$  is the distance from origin to the diagonal and  $d_2$  is the distance from the furthest

point to the diagonal. Thus the change in the values of  $d_1$  and  $d_2$  represents the change in CD value. To obtain the relative measurement result, a variable DR is defined by calculating the ratio of  $d_2$  over  $d_1$ :

$$DR = \frac{d_2}{d_1}$$

(3)

Since the diagonal bends gradually with the increase of CD, the value of DR will increase with the increase of CD. Simultaneously monitoring of OSNR and CD can be realized.

### III. EXPERIMENT SETUP AND RESULTS

Fig. 3 shows the experiment setup of the proposed scheme for simultaneously monitoring of CD and OSNR by using asynchronous delay-tap sampling and image segmentation technique. This method does not need clock signal and the sampling rate can be very low. The effectiveness of the monitoring method was experimentally demonstrated for a 10 Gb/s NRZ-OOK system. A tunable laser worked at 1550 nm was externally modulated with a Mach-Zehnder modulator by a 10 Gb/s pseudo-random bit sequence (PRBS) signal with length of  $2^{31}-1$  to generate the NRZ-OOK signals. An EDFA and an optical attenuator were used to produce different levels of ASE noise to adjust the OSNR values and noise output was combined with the

modulated data signal through a 3-dB coupler. The OSNR value was adjusted from 14 to 30 dB in the experiment. The combined noise and the data signal were amplified by another EDFA and then launched into different length of single mode fiber (SMF) which was used to introduce different amount of CD. The signal was tapped by a 10:90 coupler for conventional OSNR measurement with an optical spectrum analyzer (OSA) while the other signal passed through a bandpass filter with 3 dB bandwidth of 0.6 nm. The arrived optical signals were detected by a 10 GHz photodiode. The electrical output signal was split into X and Y channels by a 3-dB splitter. The time delay  $\tau$  between two channels was set as 1 bit period by an electrical delay line then the two channel signals were fed into a digital communications analyzer (DCA) from Agilent technologies. The sampled data were collected from the DCA and processed by a signal processing module for the further scatter plots construction and image processing.

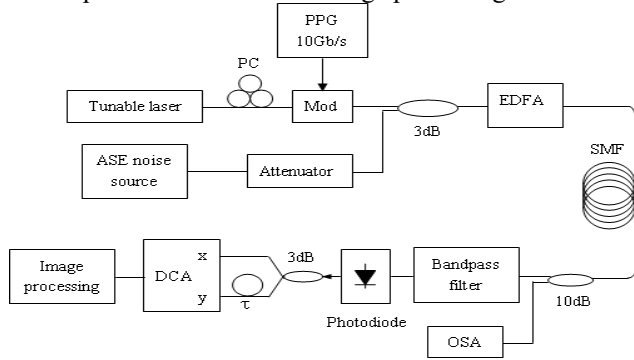


Fig. 3 Experimental setup for the proposed method.

Fig. 4 shows the measured OSNR value of 10 Gb/s NRZ-OOK signals as a function of the OSNR levels measured with conventional measurements by linear interpolation. The values measured by proposed delay-tap sampling and imaging segmentation method agree well with the results obtained from the OSA. The monitoring range is from 14 dB to 30 dB for NRZ-OOK signal. The results in Fig. 4 indicate that the accuracy of this technique is better than 1 dB and monitoring range is around 16 dB.

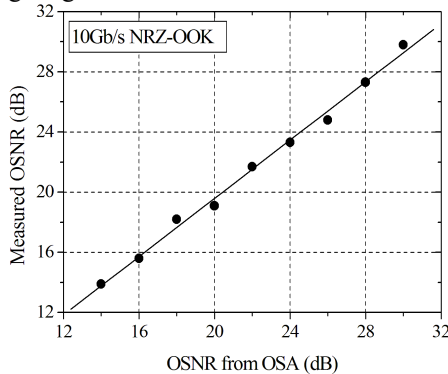


Fig. 4 OSNR measured by the proposed method as a function of the reference OSNR measured by an OSA.

Fig. 5 shows the OSNR independent CD monitoring results based on the proposed technique. The monitoring range can reach 1275 ps/nm. The distance ratio DR is equal

to 1 when CD value is 0 ps/nm. The value of DR starts to increase with the increase of CD. When the CD is larger than 1275 ps/nm, the signal delay-tap plots distorted so severely and it is difficult to extract the contour of the image. The monitoring results for CD when there is no noise added and the simulation, experimental results when OSNR is 20 dB are plotted in Fig. 5 together for comparison. The monitoring results verify that the CD monitoring results are independent of OSNR.

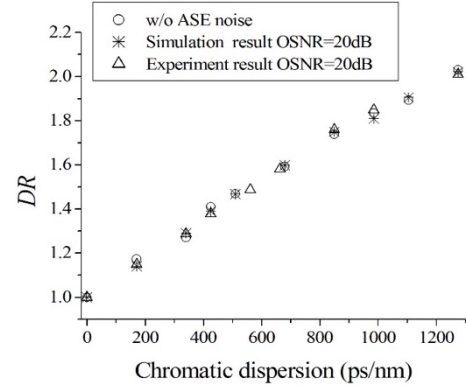


Fig. 5 CD monitoring results by using image segmentation and contraction technique.

#### IV. CONCLUSIONS

We demonstrated a simultaneous monitoring method of CD and OSNR for NRZ-OOK signals base on delay-tap sampling and image processing technique. The image segmentation method was introduced in OPM for the first time to separate OSNR and CD in the delay-tap scatter plots. The OSNR monitoring range is from 14 to 30 dB with less than 1 dB error and the CD monitoring range can go up to 1275 ps/nm.

#### REFERENCES

- [1] M. Petersen, Z. Pan, S. Lee, S. Havstad and A. Willner, "Online chromatic dispersion monitoring and compensation using a single inband subcarrier tone," IEEE Photon. Technol. Lett., vol. 14, no. 4, pp.570-572, 2002.
- [2] J. Yang, C. Yu, L. Cheng, Z. Li, C. Lu, A. P. T. Lau, H. Tam, and P. K. A. Wai, "CD-insensitive PMD monitoring based on RF power measurement," Opt. Express, vol. 19, no. 2, pp. 1354-1359, 2011.
- [3] C. Zhu, A. V. Tran, S. Chen, L. B. Du, C. C. Do, T. Anderson, A. J. Lowery, and E. Skafidas, "Statistical moments-based OSNR monitoring for coherent optical systems," Opt. Express, vol. 20, no. 16, pp. 17711-17721, 2012.
- [4] S. D. Dods and T. B. Anderson, "Optical performance monitoring technique using delay tap asynchronous waveform sampling," in Tech. Dig. Optical Fiber Communications (OFC2006), paper OThP5.
- [5] D. Wang, C. Lu, A. P. T. Lau and S. He, "Adaptive chromatic dispersion compensation for coherent communication systems using delay-tap sampling technique," IEEE Photon. Technol. Lett., vol. 23, no. 14, pp. 1016-1018, 2011.
- [6] D. Tang, X. Wang, L. Zhuang, P. Guo, A. Yang and Y. Qiao, "Delay-tap-sampling-based chromatic dispersion estimation method with ultra-low sampling rate for optical fiber communication systems," IEEE Access, vol. 8, pp. 101004-101013, 2020.
- [7] F. N. Khan, C. H. Teow, S. G. Kiu, M. C. Tan, Y. Zhou, W. H. Al-Arashi, A. P. T. Lau and C. Lu, "Automatic modulation format/bit-rate classification and signal-to-noise ratio estimation using

- asynchronous delay-tap sampling,” *Computers & Electrical Engineering*, vol. 47, pp. 126-133, 2015.
- [8] X. Liu, Y.-H. Kao, S. Chandrasekhar, I. Kang, S. Cabot, and L. L. Buhl, “OSNR monitoring method for OOK and DPSK based on optical delay interferometer,” *IEEE Photon. Technol. Lett.* vol.19, no. 15, pp. 1172 -1174, 2007.
- [9] G. P. Agrawal, *Fiber-optic communication system*, 3rd Edition. Singapore: John Wiley and Sons, pp.250-266, 1992.
- [10] Y. Deng and B. Manjunath, “Unsupervised segmentation of color-texture regions in images and video,” *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 23, no. 8, pp. 800-810, 2001.